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# Measuring the Quality of Ski Edges

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MEASURING THE QUALITY OF SKI EDGES

A Major Qualifying Project Report:

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

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**Jason Hopkins**

**Michael Dragonas**

**Frank Bruton**

Date: April 25<sup>th</sup>, 2013

## Abstract

The objective of this project is to design and manufacture an instrument for measuring the quality of ski and snowboard edges. Over the course of even one run, edges can start to dull, thus decreasing their ability to perform. Although methods including running your thumb or thumb nail against the edge of the ski are current methods for checking the sharpness of a ski edge, no products yet exist to qualitatively measure the sharpness of a ski edge. The design functions were decomposed with the design solution in a hierarchical manner consistent with axiomatic design. The resulting product appears to have satisfied the parameters of a working ski tester prototype and was fully manufactured in order to begin further testing.

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# 1 Introduction

## 1.1 Objective

The objective of this project is to design and manufacture an instrument for measuring the quality of ski edges.

## 1.2 Rationale

Between the years of 2009 and 2012, the amount of people participating in alpine skiing, snowboarding and cross country skiing averaged over 10 million alpine skiers, 7 million snowboarders and 4 million cross country skiers (SIA 2012). Among those participating from 2009-2011, an average of 60 million people skied on the mountains in the United States alone (Barry 2011). Due to the popularity of these snow sports, it is essential that the participants in this sport take good care of their equipment in order to prevent injury, equipment malfunction and performance inhibiting damages. One aspect of ski equipment care is the steel edges of the ski that are essential for proper movement and enhanced performance while skiing.

Over the course of even one run, these ski edges will start to round and incur damages such as scratches and burrs. To rid the edge of these deformities, the edge must be tuned at a snow sport specialty store or with the use of additional equipment. From 2011 – 2012, the total amount of equipment and accessories, including tuning accessories, bought at snow sports specialty stores or purchased online equated to over 1.5 billion dollars (SIA 2012). This survey displays the obvious interest in the snow sports industry, however, it does not yet include tools that check and determine the quality of the ski edge before and after tuning.

By simulating the forces of a skier carving, the force at which the ski edge would slip can be determined. Our device is a simple simulation of this action that uses the result of this friction test to determine the quality and sharpness of the ski edge. Additionally, this tool could accomplish similar goals with other cutting apparatuses such as manufacturing tools and medical instruments.

## **1.3 State-of-the-Art**

### **1.3.1 Methods for Measuring Cutting Edges**

In the past, and through the present, measuring the quality, or sharpness, of cutting edges has been conducted by simple tests rather than mathematical and scientific methods. To test the sharpness of scissors in a barber shop, the barber generally will moisten the nail then draw it down the length of edge. If the nail catches, the blade must be smoothed out. If the nail glides effortlessly down the blade, it is too dull but if the edge slightly cuts into the nail then the bevel has been set properly (Straight Razor Place 2011). A slightly less crude method is with the use of a string. In this test, the sharpness of the edge is considered a direct correlation to the amount of force necessary for the blade to cut through a loop of thread. Using a loop of thread attached to the small spring scale, the force is measured and a corresponding table is included for how much force is required for a knife blade dependent on its woodworking uses.

### **1.3.2 Current Products for Measuring Cutting Edges**

Besides the simpler methods listed above, there are several products in the market that test the sharpness of cutting edges. Developed by the Cutlery & Allied Traders Research Association (CATRA) are several types of products specifically for knives, blades, razors scalpels and machine blades. Examples of such products are the Blade Edge Profile Microscope and the Sharpness Tester (CATRA 2012). Another product developed by VOLVO, US patent 7570369, uses the concept of light scattering to determine the location of craters and burrs (Henrikson 2008). More related to the specifics of skiing is a product called



a Tuning Stick made by SkiVisions. This product uses the same simplistic idea as the thumb nail test, but instead of a human nail it uses plastic rod that when drawn down the length of the ski will show if burrs are present through the manner in which the plastic is shaved (SkiVisions 2012).

### 1.3.3 Methods of Characterizing Ski Edges

To characterize the edge of a ski, the sharpness and edge roundness of ski edges must be considered and simplified to another form of a cutting tool. This simplification can then relate the skis to machining and the cutting forces associated with machining. In an experiment done by Lieu and Mote in 1985, the skis were tested by simulating the machining of ice. By machining the ice at rake angles of  $-15^{\circ}$  to  $-60^{\circ}$ , they determined that the “cutting force components were approximately independent of cutting speed” and that “the magnitude of the resultant force increased with the negative rake angle” (Lieu & Mote 1985). To further this theory, in 1989 Brown and Outwater developed a testing device to test the ski-snow interaction and found similar results as Lieu and Mote in that skidding of the skis will occur at larger angles while holding, or carving, will occur at smaller angles.

Since the Brown and Outwater experiment, additional ski-snow interactions experiments have been conducted. In the a dissertation for the finite element simulation of carving a snow ski completed in 2005, two devices, Agenvis and the Fast Snowdeformer, were created to measure the snow resistance as a result of edging angle and constant penetration speed as well as the snow resistance as a result of different penetration speeds with a  $90^{\circ}$  angle, respectively. For Agenvis, the results concluded that an angle of more than  $40^{\circ}$  initially increases the snow resistance “rapidly, but is frequently reduced by pronounced fractures” (Federolf 2005). For the Fast Snowdeformer it was found that the penetration speed varied depending on the snow properties.

To characterize the edge itself, a study has been conducted recently using Heron’s formula to calculate the measured profile as a function position and scale (Gleason & Brown 2013).

### 1.3.4 Approach

Our design will use the concepts of previous ski edge testing devices and edge characterization to build a device that will test the edge quality, or sharpness, in a simple and effective manner.

During our design process, we utilized the Axiomatic Design process through the use of software known as Acclaro. Axiomatic Design is framework for the design process wherein “the designer with a theoretical foundation based on logical and rational thought process and tools” creates a product (Suh 2001, p.5). This framework includes Functional Requirements (FRs) and corresponding Design Parameters (DPs) that are mutually exclusive, collectively exhaustive and contain a minimum number of functional requirements. . The final axiomatic design decomposition taken from Acclaro for the purposes of this project can be found in Figure 1 below.

0	FR	measure sharpness of ski edge	DP	ski edge force ratio tester
1	FR	apply adjustable normal force	DP	spring compression assembly
1.1	FR	allow spring compressor to stay in fixed position	DP	Threaded hole with fitted screw
1.2	FR	compress springs	DP	thread screw down against horizontal top frame
1.3	FR	Impact with flat surface to compress spring	DP	screw w/ bolts & washer larger than diameter of spring
1.4	FR	Hold spring in place	DP	tube surrounding spring
1.5	FR	allow movement of test material in normal direction	DP	vertical linear bearings
1.6	FR	Restrict twisting of vert. bearings to provide correct alignment	DP	U-Frame fastened in place by horizontal bearings
1.7	FR	allow reduced friction movement in normal direction	DP	vertical linear bearings
1.8	FR	calibrate normal force	DP	calculate by spring rate*displacement = load
1.9	FR	restrict vertical bearings from sliding off tracks	DP	ledge/ screw to hold it in place at the end of the bearing rail
2	FR	apply tangential force (tan to surface)	DP	spring force
2.1	FR	attach spring to device to provide force	DP	attach to outside square frame
2.2	FR	allow reduced friction movement in tangential direction	DP	tangential bearings attached to outer frame
3	FR	control the angle of testing device	DP	axles with threads on both ends to tighten at a specific angle w/ bolt
3.1	FR	prevent angle rotating about axle	DP	bolt tightening
3.2	FR	make adjustable angle that keeps the material box on ski edge	DP	arc track
4	FR	Attach full device to ski	DP	C-clamps
4.1	FR	fasten c-clamp to ski	DP	threaded holes in c-clamp + threaded screw
4.2	FR	Prevent damage to ski surfaces w/ clamp	DP	flat disk surface with anti-scuff material
4.3	FR	attach c-clamp to arch	DP	pin/ screw to follow arch track
4.4	FR	attach arch to frame	DP	8-32 thru all screws
4.5	FR	Assemble frame prototype for ease of manufacturability	DP	divide into four pieces (fastened by 8-32 SHCS)
4.6	FR	attach frame to linear bearing rail	DP	M3 holes each side of frame
4.7	FR	attach linear bearing to vertical sides of U-frame	DP	fastened with M3 holes
4.8	FR	attach inner vert. sides of U-frame to vertical linear bearing rail	DP	M2 screw holes
4.9	FR	restrict twisting of clamps and full device	DP	clamp connector
5	FR	hold testing material	DP	box & set screws
5.1	FR	attach box holding test material to vertical bearing	DP	vertical rectangular piece screwed into box holder
5.2	FR	restrict twisting of box holder	DP	2 separate screws into box holder
5.3	FR	Attach tube with spring vertically to box holder	DP	Inner middle box
5.4	FR	provide adequate box holding strength	DP	8-32 SHCS holes to hold material in place

Figure 1: Final Design Decomposition

## 2 Design Decomposition

The primary design tactic used for this project was axiomatic design. Axiomatic design decomposes a design into different Functional Requirements (FR) and corresponding Design Parameters (DP). Functional requirements denote what needs to be accomplished by the final design and the Design parameters highlight how FR's will get carried out. Each FR should be decomposed until a solution is readily obvious. Each DP began with many options available, however, through testing and analysis, were compressed to one optimal solution these nullified DP options can be found in Appendix B. The objective of this project is to measure the sharpness of ski edges to determine when ski tuning is necessary. FR's and corresponding DP's were developed together and for the purposes of this report will be outlined per the Acclaro file found below in Figure 1.

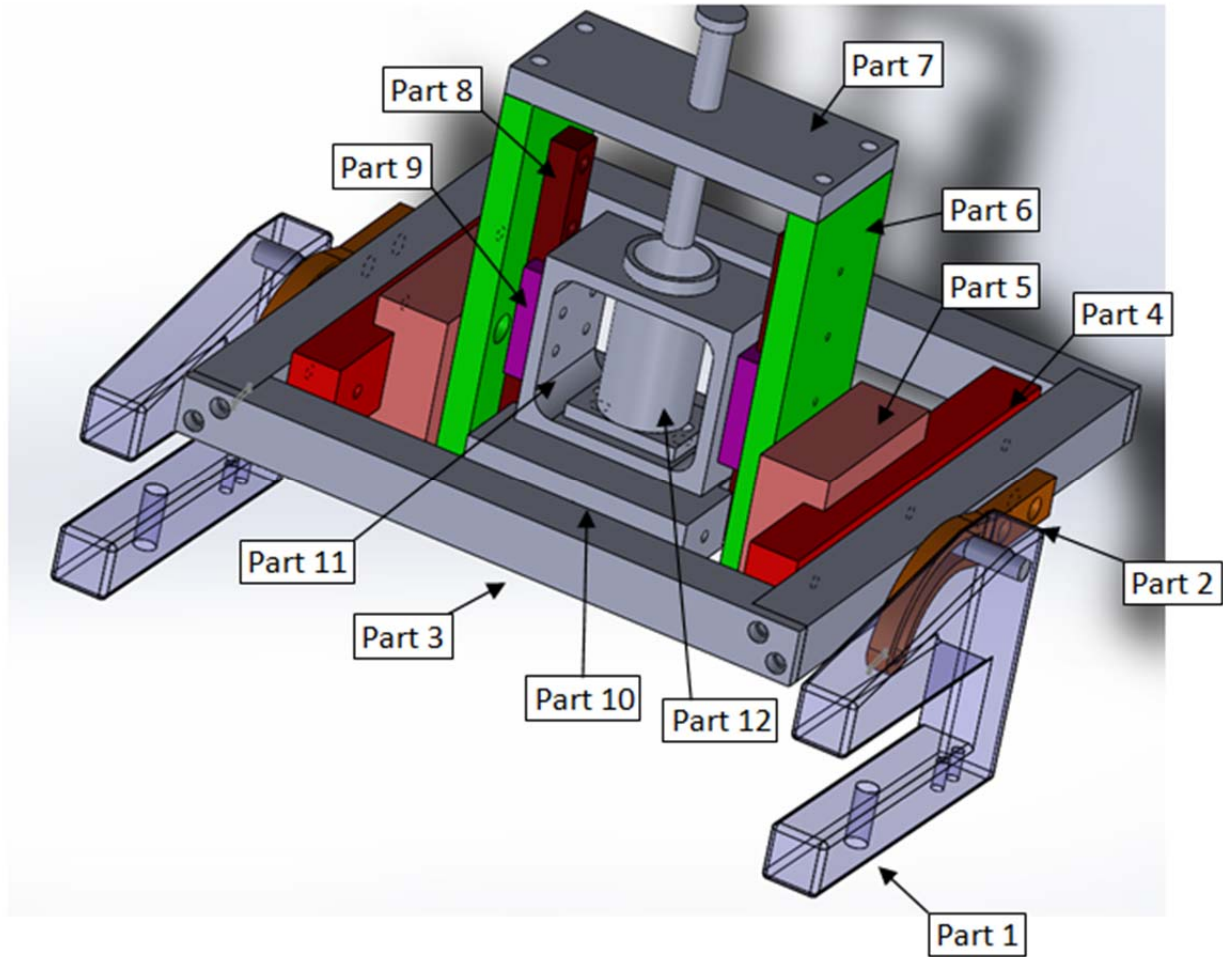


Figure 2: Overall Solid Model of Prototype

Part name	Part #	Functional Requirements
C-clamps	Part 1	FR 4
Arch	Part 2	FR 3
Square frame	Part 3	FR 4.5
Horizontal bearing rail	Part 4	FR 2.2
Horizontal bearing carriage	Part 5	FR 2.2
Vertical plate	Part 6	FR 1.5
Horizontal plate w/ threaded hole	Part 7	FR 1.1
Vertical bearing rail	Part 8	FR 1.7
Vertical bearing carriage	Part 9	FR 1.7
Material holder	Part 10	FR 5.1
Bearing-compressor connector	Part 11	FR 5.2
Spring aligning cylinder	Part 12	FR 5.3

## 2.1 FR 0- Measure sharpness of a Ski Edge

The primary objective of this project is to design a device that will clamp to a ski and by applying specific forces to the ski edge, determining when an edge needs to be tuned. This ability to define what is sharp and what is dull will allow the skier to optimize his/her skiing experience by making turning more efficient and safer. In order to accomplish this, DP 0- Ski edge force ratio tester, was developed. A three-dimensional model along with x, y, and z directions can be found above in Figure 1. An exploded view of the device with labeled upper level Functional requirements can be found in the figure below.

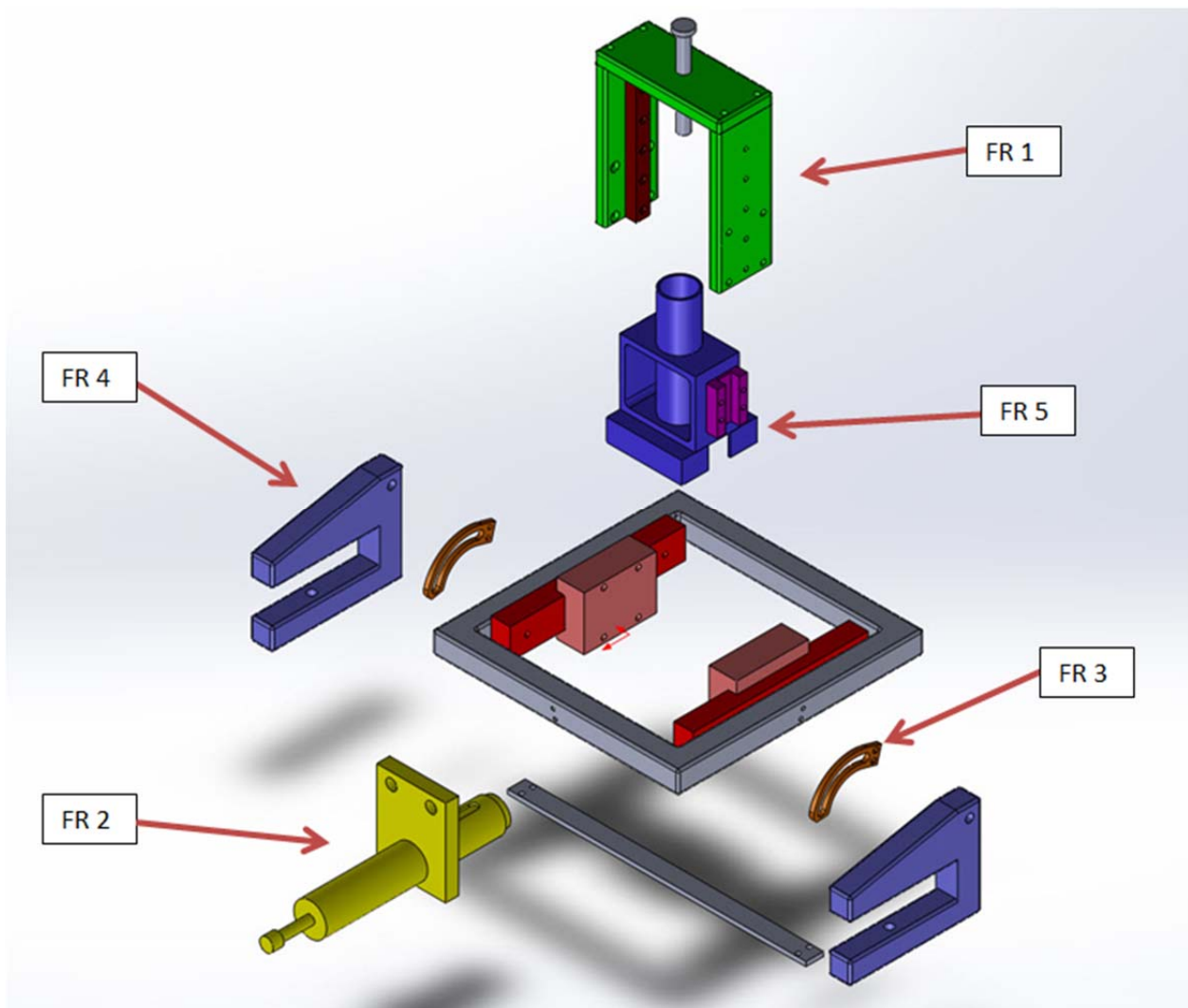


Figure 3: Exploded view of the Final Device with labeled FR's

## **2.2 FR 1- Apply adjustable normal force (normal to test surface)**

In order to simulate the force a skier applies to a ski when turning, a normal force must be applied to the ski edge. After testing and analysis, DP 1 was chosen to be a compression spring. A skier/snowboarder must turn in order to control their movement on the trail as well as slow down or stop when necessary. This DP introduces a normal force similar to the force applied from the skier pushing down to carve the edge into the snow surface.

### **2.2.1 FR 1.1 – Allow spring compressor to stay in fixed position**

In order to apply this normal force in only the downward direction, FR 1.1 states that the spring compressor must be fixed. The corresponding DP to accomplish this is a horizontal plate with a threaded hole where the compressing spring will thread through. In this design, the normal force can be variable in its application of a gradual normal force, similar to the force applied by a skier.

### **2.2.2 FR 1.2 – Compress Spring**

FR 1.2 expresses the method of applying the normal force described above with the use of a spring. A spring was chosen for its linear compression rate and the ability to adjust the force applied easily. The DP used to fulfill this FR is threading the hole in the horizontal plate, Part 7. Doing this will apply the normal force in only the downward direction.

### **2.2.3 FR 1.3 – Impact with Flat Surface to compress spring**

FR 1.3 targets the need to provide a flat surface that the spring can rest on so that all forces are distributed evenly. A simple solution to carrying out this FR, or DP 1.3, is adding a machine nut, a washer that is smaller than the inside diameter of the spring, and another nut to hold it in place. This will ensure that the spring will be compressed and will provide an evenly distributed normal force.

#### **2.2.4 FR 1.4 – Hold Spring in Place**

To avoid the spring bowing to one side and possibly distorting the applied normal force, FR 1.4 was developed to ensure only a vertical force. The DP to accomplish this FR will be a piece of aluminum piping that protrudes from the box holding the ice that touches the edge. This piping will have a large enough inside diameter to fit the spring inside it, with minimal room for bowing when the normal force is applied.

#### **2.2.5 FR 1.5 – Allow movement of test material in normal direction**

In order to apply the normal force correctly, FR 1.5 the material touching the ice must be able to move in the normal direction. DP 1.5 states that this will be accomplished by attaching the bearing-compressor connector box to vertical linear bearings attached in the direction of the normal force. This will allow the testing material to scrape along the edge when the tangential force is applied.

#### **2.2.6 FR 1.6- Restrict twisting of vertical bearings to provide correct alignment**

When a tangential force is applied to the testing material that is touching the ski edge, due to imperfections in the ice surface, the ice could twist or “hop” as it moves across this ski edge. FR 1.6 was derived to restrict this movement. The DP to accomplish this was attaching the vertical linear bearings to an outside “U-frame” that will then be attached to the horizontal linear bearings. With these two attachment points, the inner box holding the testing material and the vertical bearings cannot twist in any direction.

#### **2.2.7 FR 1.7 – Allow reduced friction movement in normal direction**

FR 1.7 describes the need to allow the testing material to move freely in the y-direction independently of the rest of the device. DP 1.7 states that vertical bearings will be installed in order to allow this movement. These vertical bearings will allow the compressing spring to push the testing

material down on the edge and also move with the material as it slips with the least amount of friction possible.

### **2.3 FR 2.0 – Apply tangential force**

This design encompasses two main forces on the ski edge during skiing. The normal force, which simulates the weight and force applied of the skier, and the tangential force which simulates the slipping of the ski edge over the snow when the edge is carved into the snow. FR 2.0 targets this tangential force specifically. This tangential force must be applied to the material that is touching the ski edge. DP 2.0 applies this tangential force by attaching a compression spring, in a similar fashion to the vertical compression spring set-up, from the outer frame to the box holding the piece of ice touching the edge. This force will simulate the force of the skier slipping on the snow/ice surface.

#### **2.3.1 FR 2.1 - Attach spring to device to provide tangential force**

In order to apply the tangential force mentioned above, FR 2.1 calls for a spring being attached to the mechanism. To carry this out, DP 2.1 calls for a small flat piece of aluminum be attached to the outside edge to the Frame with a non-threaded hole in it that is in line with the box holding the material. Also on this piece of aluminum will be an aluminum tube with a cap that has a threaded hole in it. Inside this threaded hole, a screw will go through, make contact with the compression spring, which will push a pin through the non-threaded hole to thus apply the tangential force. See figure 1 for details.

#### **2.3.2 FR 2.2 – Allow reduced friction movement in tangential direction**

FR 2.5 allows for movement in the tangential direction to the ski edge. In order to accomplish this, DP 2.5 states that linear bearings will be attached to the outside frame to allow the testing material to slip tangentially across the ski edge.



## **2.4 FR 3.0- Control the angle of the testing device**

In order to accurately simulate the angle a skier makes when turning or carving in the snow, it is imperative that this device has a variable angle so that these different conditions can be tested. A variable angle will also allow us to find the optimal angle for testing and analyzing the most accurate determination of sharp edges and dull edges.

### **2.4.1 FR 3.1 – Prevent angle rotating about axle**

FR 3.2 restrains the rotation about the testing material on the edge. Once this angle is set to its desired location, it must be held at that angle through the testing period. DP 3.2 will lock the frame in place by tightening nuts through the ski clamps on each side. Tightening these nuts will compress the clamps to the frame and lock the frame in place.

### **2.4.2 FR 3.2 – Make adjustable angle that keeps the material box on ski edge**

In order to rotate the material holder and material around the edge uniformly, the edge of the ski has to act as the center of rotation for the device. For this reason FR 3.3 states that the device must be allowed to rotate around the edge as opposed to a center of rotation off the edge. DP 3.3 adds an arching track with a radius from where the DP 3.2 holes are to the edge of the ice. This radius will allow rotation about the edge so that all moments are as close to the edge as possible.

## **2.5 FR 4- Attach full device to ski**

In order to accurately test the edge it is important to have the ski fully attached to the device to restrain motion and allow all of the integral pieces to correctly perform their functions. FR 4.0 begins to address this need by prescribing an attachment to the ski from the device. DP 4.0 creates this attachment via two c-clamps.

### **2.5.1 FR 4.1- Fasten C-Clamps to ski**

FR 4.1 highlights the need to create a fastener between the c-clamps and the ski in order to be rendered effective per FR4.0. In order to accomplish this, DP 4.1 states a combination of threaded holes and a threaded screw will be used in order to create the necessary fastening.

### **2.5.2 FR 4.2- Prevent damage to ski surface from clamp fastener**

In order to provide an effective device to the customer it must not cause damage to the actual ski itself. This concept is addressed by FR 4.2 stating that the clamp shall not damage the ski surface. This is accomplished by attaching a flat disc surface with an anti-scuff material adhered to the threaded screw used in DP 4.1 per DP 4.2.

### **2.5.3 FR 4.3- Attach C-Clamp to arch**

FR 4.3 outlines the need to attach the c-clamp to the arch used on the frame. This arch will provide angle adjustment mentioned in FR 3.3 but in order to provide this function the attachment to the c-clamp must allow for the track to move without detaching itself completely. In order to accomplish this, DP 4.3 provides for a pin and screw to follow the arch track and the inner lip will hold it in place.

### **2.5.4 FR 4.4- Attach arch to frame**

FR 4.4 shows that the arch must be attached to the frame. In order to accomplish this two through holes must be used with screws in order to prevent twisting and this is shown through DP 4.4 with 8-32 through all screws.

### **2.5.5 FR 4.5- Assemble frame prototype for ease of manufacturability**

FR 4.5 demonstrates the need to adjust the design concept in order to provide ease of manufacturing. Cutting a solid square out of a large stock piece of aluminum would create a large amount of wasted scrap so DP 4.5 provides for the frame to be divided into four pieces, which are fastened by 8-32 SHCS, in order to provide for ease of manufacturability.

### **2.5.6 FR 4.6- Attach frame to linear bearing rail**

FR 4.6 outlines the need to attach the frame to the horizontal linear bearing rails. These two rails have predrilled holes therefore three of the appropriate M3 holes had to be mimicked on the inside of two opposite beams of the frame per DP 4.5.

### **2.5.7 FR 4.7- Attach linear bearing to vertical sides of U-frame**

In order to provide for motion in the normal direction per FR 1.5 it is necessary to create an attachment point for the vertical bearings that runs in the proper normal direction to the test point location. FR 4.7 solves this by outlining the need for the linear bearings to be attached to the vertical sides of the U-frame created by the vertical and horizontal plates. This is done through fastening with M3 holes per DP 4.7.

### **2.5.8 FR 4.8- Attach inner vertical sides of U-frame to vertical bearing rail**

FR 4.8 demonstrates the need to provide for attachment of the vertical bearing rail to the vertical sides of the U-frame in order to allow for the normal motion prescribed in FR 1.5. This is accomplished through DP 4.8 with M2 screw holes, which match the predrilled holes from the manufactured vertical bearing rail.

### **2.5.9 FR 4.9- Restrict twisting of clamps and full device**

In order to provide for a solid device that has the stability necessary to provide for a testing environment it must be restricted from twisting per FR 4.9. This is accomplished by keep the clamps lined up with a connector between the clamps per DP 4.9.

## **2.6 FR 5- Hold testing material**

In order to effectively use the testing material to provide results via the device, the material must be held effectively in place with no movement or twisting. The test material being held in place will allow for accurate and meaningful results to be discerned from subsequent test. This FR 6.0 will be

accomplished through DP 6.0 allowing for a box, material holder, to hold the test material and a set of screws to keep it solidly in position.

#### **2.6.1 FR 5.1- Attach box holding test material to vertical bearing**

In order to transmit the normal forces applied via FR1.0, the material holder must be held in place securely. DP 5.1 uses a vertical plate screwed into the material holder in order to accomplish this functional requirement.

#### **2.6.2 FR 5.2 – Restrict twisting of material holder**

In order to ensure that all normal and tangential forces are properly applied there cannot be any twisting of the material holder, which could damage the testing environment and invalidate results. This is taken care of with FR 5.2, which is to restrict twisting of the material holder and is accomplished by having two separate holes into the material holder.

#### **2.6.3 FR 5.3- Attach tube with spring vertically to material holder**

In order to provide for the normal force describe in FR 1.0 to be transmitted in the correct direction the tube must be attached to the material holder vertically per FR 5.3. This is accomplished through the spring aligning cylinder which holds it in place per DP 5.3

#### **2.6.4 FR 5.4- Provide adequate material holding strength**

To ensure that the material does not move after loads are applied there must be adequate material holding strength per FR 5.4. This will be accomplished by DP 5.4, stating there will be 8-32 SHCS holes to hold the material in place.

### **3 Prototype Production**

To produce the prototype, there were many parts that had to be manufactured exactly to our specifications in order for the pieces to integrate correctly with one another. The features necessary to

produce this outcome were created and simulated through computer aided manufacturing (CAM) software called ESPRIT. Using these files as a guide, most of the parts were able to be manufactured using a HAAS Minimill.

All of the parts were made using 6061-T6 Aluminum stock metal. Aluminum was chosen because the prototype needed to be easily manufactured and inexpensive. Additionally, the prototype will not be subject to extensive forces therefore the metallographic properties of Aluminum will suffice for the success of this prototype.

### 3.1 Ski Clamps

To create this part from its stock material to the correct specifications, it first needed to be faced down until the opposite sides of the piece were parallel to one another. In order to do this the stock was cut initially with a band saw, and then faced using the HAAS minimill. Some errors were made during this process due to an overaggressive approach to facing, however these errors were not repeated and the remaining material was salvaged. To make the features for this part, ESPRIT files were created to account for each set of features on the part that needed to be held in a different manner.

The first step of creating the ski clamps was to drill the holes on the bottom surface that will be

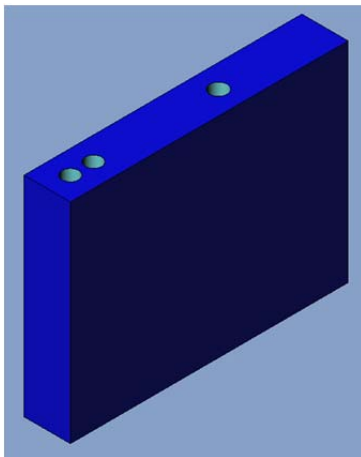


Figure 3: Simulation of Step 1 of creating the ski clamps

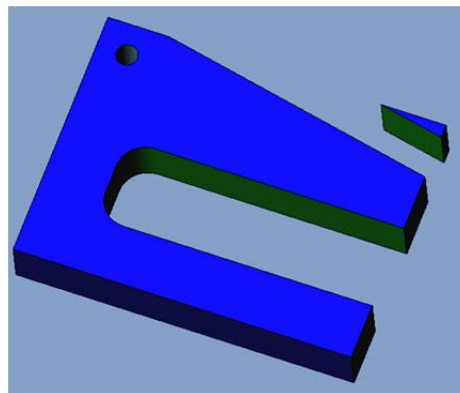


Figure 2: Simulation of Step 2 of creating the ski clamps

used to fasten more additional parts. The second step included milling out the pocket within the part where a ski would be located as well as the hole necessary for connect the ski clamps to the inner mechanisms of the device.

### 3.2 Frames

The original frame designed for this project was altered for the prototype to make easier to manufacture and more cost and material effective. It was broken up in four simple parts, two sets of square rods that interacted with one another through a key function.

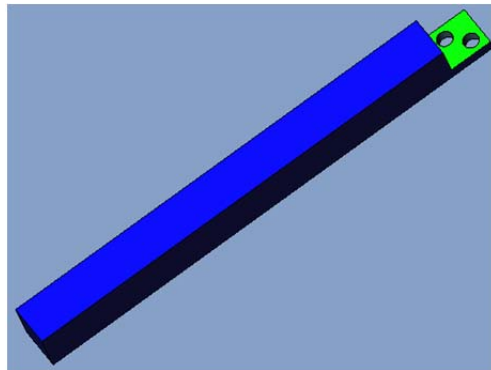


Figure 4: Frame with key function shown

To produce these pieces, ESPRIT files were used to drill the holes on the length on the square rods in addition to creating the step feature shown as a key function above. The holes on the ends of the non-step rods were created using a drill press. All of the holes were hand-tapped and assembled using 8/32 socket head cap screws.

### 3.3 Vertical Bearing Casing Plates

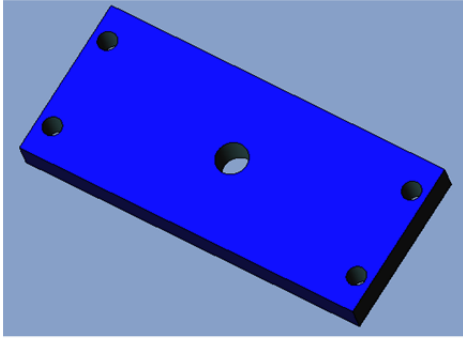


Figure 6: Top of U-Frame

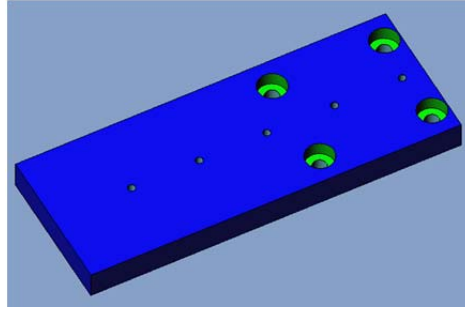


Figure 5: Sides of U-Frame

The three pieces necessary to produce the U-shaped casing around the vertical bearings were sensitive to the size of the holes of the pre-drilled linear bearing rails and carriages that they interface with. For all of the holes on the faces on the parts a HAAS Minimill was used. For the ends of the pieces, the holes were drill pressed.

### 3.4 Arch Pieces

The side arch pieces were produced at the same time on the HAAS Minimill. Both pieces had to be bolted a scrap piece of metal to ensure that they would not move out of place during the machining.

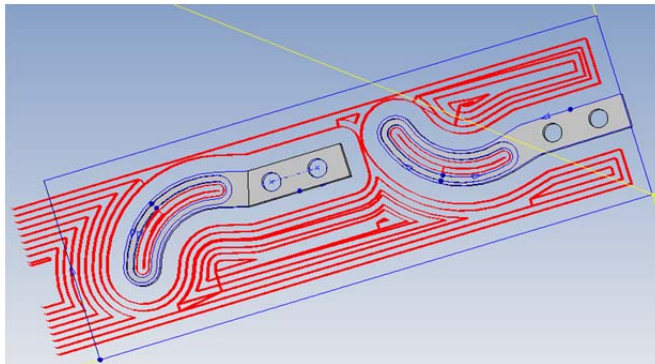


Figure 7: ESPRIT file of Arch Pieces

### 3.5 Middle Spring Holder

After several solid modeling design iterations, the middle spring holder that facilitates the normal force was finalized and manufactured on HAAS Minimill. There are features on almost every face of this part therefore the stock material had to be re-oriented for each face with its own ESPRIT file. First the top and bottom hole cut-outs for the spring and the screw holes were milled. Then, the inside pocket

feature of this part was milled out followed by the screw holes required to hold onto the inner vertical bearings.

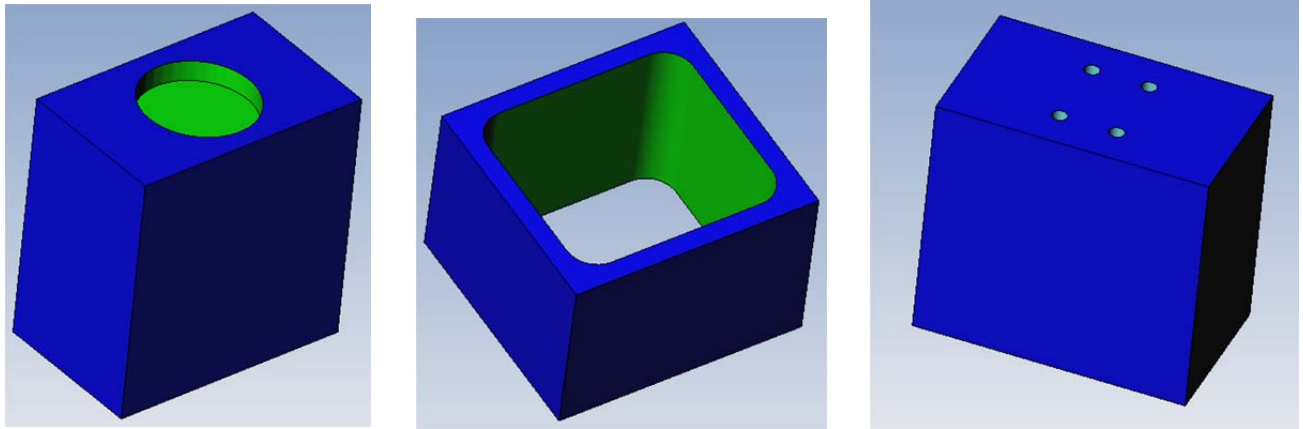


Figure 8: Steps 1, 2 and 3 of the production via ESPRIT

### 3.8 Box Holder

The box that holds the testing material was also milled on the HAAS Minimill.

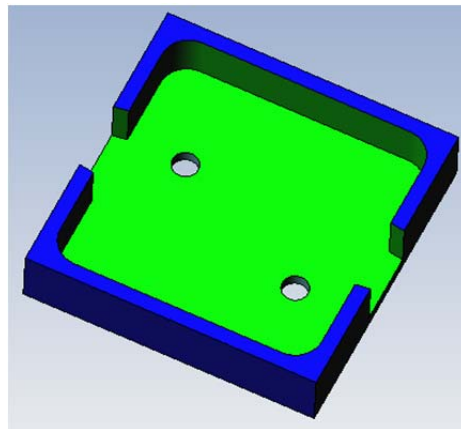


Figure 9: Box holder

### 3.9 Additional pieces

Several additional pieces were manufactured by hand without the aid of Espirit or the HAAS Minimill. The reasoning behind skipping the milling steps for these parts was for ease of machining, speed, and the fact that these pieces were simple. The handle on the vertical spring is the first example of an additional piece. This was a section of solid cylindrical tubing cut down to the proper size in order



to be able to turn obstruction free. This piece then had a hole tapped in the center to allow the rod, which impacts the spring, to be attached and is pictured below in Figure 10.



**Figure 10: Handle Assembly**

The next additional piece was the screw assembly for the ski clamp. This screw top had to have an attachment, so damage would not be done to the underside of skis while being clamped in. This was accomplished by attaching a cylindrical plate, which was cut down from a larger pre-manufactured cylinder, to the screw using side bolts in order to lock it in place and is pictured below in Figure 11. Having this assembly allowed for protection to the ski in a form that will not wind off of the screw during the process of clamping and unclamping the ski.



Figure 11: Screw Assembly

The final additional piece was for the application of a tangential force. This again was of simple design using parts readily available so milling was skipped. In this case tubing was cut down to the appropriate size to allow for the spring to be held within the correct alignment. A notch was cut out at the top of one end of the tubing so a set screw could be attached to the inner cylinder. This inner cylinder applies the spring force to the box holder and the set screw is used to contain this inner cylinder from sliding out. A cap was then rigged on the other end of the hollow tube to allow for a screw to apply force to compress the spring and the entire assembly was attached to the frame arm in order to allow for proper application of the tangential force to the box holder. This assembly is pictured below in Figure 12.

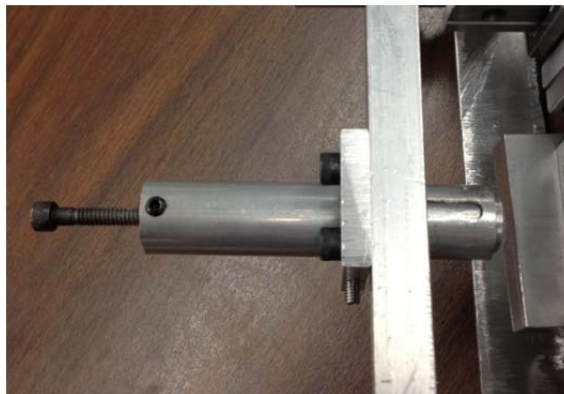


Figure 12: Tangential Force Assembly

## 4 Testing

Once the device had been manufactured, testing needed to be conducted to prove the viability of the device. In each test, each feature was utilized to ensure proper functionality within the device. A testing procedure was developed by first, Inserting testing material into the material holder and securing with set screws. Next, the device is clamped to the ski via the ski clamps and the clamping mechanism. For this step, ensure that the ski edge is securely fastened up against the back of the clamp and that the material holder is touching the ski edge to be tested. Once this has been completed, adjust the square frame to the desired angle using a protractor and lock in place using the clamping mechanism on the ski clamp. Next, apply a normal force on the material which is touching the edge. Finally, with the proper normal force being applied, compress the spring in the tangential direction using the compressor spring. One of two things will happen: either the spring will compress all the way with no movement on the ice, which means that the ski edge is sharp and tuning is not required, or the material will slip on the edge, which is evidence that the edge needs to be tuned.

For the testing phase of the project, a polyethylene piece was used in the material holder with a larger piece of polyethylene clamped into the device. A friction test was first completed to determine the coefficient of friction of polyethylene on polyethylene. In this test a block of polyethylene was prepared with a smooth face and the edges were rounded. This was done to avoid anomalies in the friction data as a result of previous damage and the frayed edge caused by the cutting blade. The surface of the polyethylene testing surface was then analyzed for similar damage. Once satisfied a common location for the block to begin was chosen to avoid variance from unwanted variables. With setup complete, the bottom surface was tilted upwards about a pivot point until the block began to first slide. This angle was then measured with a protractor to be used in later calculations. The test was completed 8 times in order to check for repeatability and to create an average angle of slip. The block

was then also weighed on a chemical scale for later calculations. The following table contains trial data and is followed by calculations for the coefficient of friction in this system.

**Table 1: Results from polyethylene on polyethylene coefficient of friction test**

Trail #	Angle of Slip (degrees)
1	24
2	22
3	20
4	21
5	23
6	20
7	21
8	24
Average	21.875
Mass	18.9948g

$$\Sigma x = f - 0.1863 \sin(21.875) = 0$$

$$F = 0.0694$$

$$y = N - 0.1863 \cos(21.875) = 0$$

$$N = 0.1728$$

$$F = \mu N$$

$$\mu = \frac{F}{N} = \frac{0.0694}{0.1728} = 0.402$$

Theoretically, the coefficient of the friction determined from the angle test should be the same, or similar, to the coefficient of friction that can be found using the ski edge prototype. To test this, three trials were run at a fixed angle of 30° and at different applied normal forces. Once set up, the tangential force was adjusted until the device slipped. Due to the bearing alignment issues present in the design the horizontal linear bearings had limited sliding abilities. This additional tangential friction force caused the tangential spring assembly to max out at about 11.3 lbs for all normal force applications. Shown below is a table with the various normal force applications used in this testing procedure.

**Table 2: Tangential force testing results**

Normal force (lbs)	Tangential force at slip (lbs)
10	>11.3
2.5	>11.3
0	>11.3

## 5 Discussion

Through the logical progression outlined by Axiomatic Design, a prototype for measuring the quality of ski edges was developed. Once this process was fully understood, it was an extremely useful tool to evaluate the options and constraints that were necessary for a successful outcome. When multiple design parameter options fulfilled a single functional requirement, design decisions were made with the aid of solid modeling and decided upon with functionality, cost, and manufacturability in mind.

### 5.1 Design Process Complications

Prior to using Axiomatic Design to a greater degree, it was difficult to agree upon a course of action and refine it until it was able to be manufactured. Original ideas included a device similar to one used to by Brown and Outwater for their work with ski-snow interactions. Instead of altering just the tangential force vs. radius of curvature of the ski edge, the angle was altered while a single operator applied a normal force to the ski edge. Various tests with different radiuses of curvature were completed with the intent of determining a quantifiable definition of sharpness. Due to variables such as operator error, inconsistent normal and tangential forces and material hardness, these tests were inconclusive.

To reduce the amount of variables that were encountered, further designs were brainstormed where the normal and tangential forces were fixed and the angle was still altered. These designs still yielded variable complications as well as overly complicated angle calculations. An initial design decomposition found in the figure 10 was formed however it was soon decided that altering the tangential force while restricting the normal force and angle was a more ideal option.

0	FR	Make edge slide on ice	DP	device that allows edge to slide on ice
1	FR	restrict vertical movement & twisting	DP	linear bearings attached to platform
2	FR	allow tangential movement	DP	bearings
3	FR	reduce friction between all parts	DP	lubricant
4	FR	produce axial rotation of ice	DP	fill sack with air at constant rate & air pressure
5	FR	hold edge at 45 degrees to ice	DP	screws on either side of steel
6	FR	load close to edge to reduce moment arm	DP	weights on hooks on either side
7	FR	contact between ice & edge	DP	shims underneath ice to raise it to the ice

Figure 13: Axiomatic design decomposition for angle tester

Several Solidworks models were developed for options with the tangential force tester. Each part was made to serve a specific purpose and was thus altered to fit that purpose more efficiently as the design process continued. At this stage iterations became involved in order to successfully machine the final device. These iterations were born out of necessity for both capability of machining based on fixturing and ease of machining regarding wasted stock material and tool design paths. At this stage iterations were all for the aforementioned reasons and were not born out of a need to change the design in order to achieve a successful working model that would complete the design goals. These iterations were necessary in the design process but very well could have been avoided. If manufacturing had been considered and consulted at an earlier stage, tedious iterations would not have occurred, which usually involved more than one piece that functioned together. Once a sufficient design was agreed upon to accomplish all goals, the manufacturing process began. While working with the help of the machine shop, some parts were slightly changed for ease of manufacturing, but did not change the part's overall purpose.

Manufacturing the parts themselves took much longer than was expected, but the all of the parts were completed are in working order. It is in part because of axiomatic design that all design parameters and functional requirements were considered so in the end no parts needed to be redesigned or remanufactured after initial machining was completed. This achievement saved hours of work and hardship while allowing the project to move in a forward direction.

## 5.2 Lesson Learnt

Many of the complications listed above could have been avoided through an earlier use of the Axiomatic Design process and clearer design intent. Possible tools to prevent problems later down the design process could have been matrices and flowcharts, which could have weeded out potential issue before a design was constructed. It was also difficult to determine a specific design idea because this project had the potential for many opportunities. However, with a better understanding of the design process and when to use mechanisms such as pneumatic, hydraulic and electromagnetic devices, it would be much easier to do this project.

Further, much more could have been completed with this project had there been more time allotted to machining and manufacturing.

## 5.3 Improvements for Prototype

To improve upon the prototype, there are several small variations that could be made. First of all, the bearings currently in place are simple linear bearings. Linear ball bearings would reduce the friction of the inner assembly, thus reducing an outside force on the system. Other parts in the device that could be changed are the spring action normal and tangential force applicators. These applicators could be changed to pneumatic actuators or powered by electromagnetic forces.

As for the prototype as a whole, the tolerances could be tighter within the device since the main components lie within a set frame where alignment is critical. This alignment could be fixed by allowing for more leeway within the components or by improving machining to better perfect the alignment and allow the bearings to perform as intended. Further, a finalized device could be more aesthetically pleasing to appeal to marketing purposes. This could be done by rounding the sides more, using more flush screws and adding a type of plastic covering to hide the inner mechanisms.

## 5.4 Future Work

In the future, this device will be used to further analyze the relationship between the applied force and the radius of curvature of an edge using methods developed by Gleason and Brown. By testing several steel edges with different radiuses of curvature and the same applied normal force, the edge characterization methods used by Gleason and Brown will quantifiably define the sharpness of an edge. The edges are currently prepped and ready for testing now, as is detailed in Appendix A. In a practical use of this prototype the data collected from the analysis will determine the sharpness of an edge.

## 5.5 Marketability

Although this device was directed for use with ski edges, it has the potential to be used with an assortment of other cutting edges such as cutting knives, surgical tools and machining tools.

## 6 Conclusion

During the course of one run, ski and snowboard edges can round and lose their sharpness. However, it is very difficult to determine to what degree this rounding occurs. The intent of this prototype was to quantifiably determine the sharpness of the edge. The device was designed and manufactured as a prototype to further validate that it can use force and the radius of curvature to define the sharpness of an edge. This device can potentially be very marketable for snow sports because there is not yet a quantifiable method for measuring the quality of ski edges.

This theory can also apply to other cutting edges such as cutting knives, surgical and machining tools, thus the prototype created can be retrofitted to accommodate other cutting tools. This device is also very marketable for cutting tools in general due to its flexibility between different types of cutting tools.



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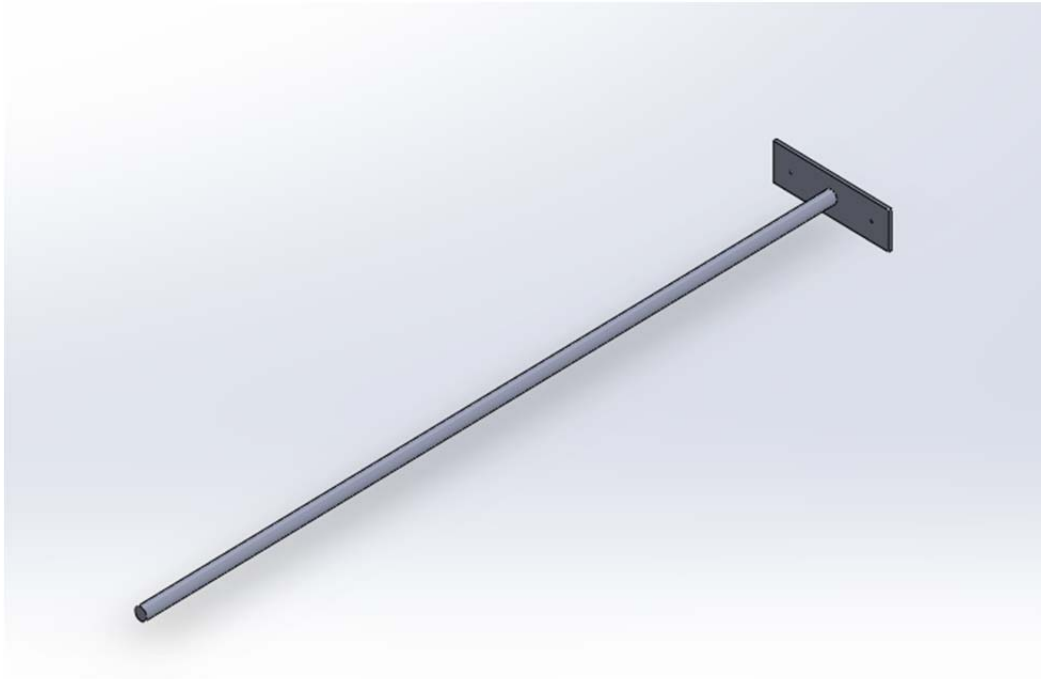
[http://straightrazorplace.com/srpwiki/index.php/Sharpness\\_tests\\_explained](http://straightrazorplace.com/srpwiki/index.php/Sharpness_tests_explained)

## Appendix A: Ski edge Prep

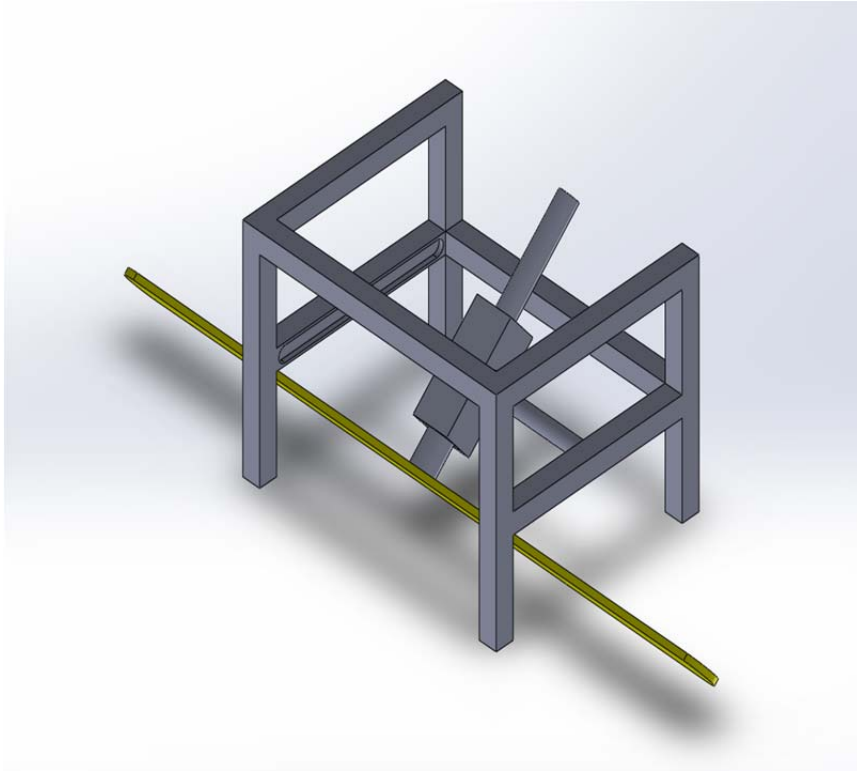
In order to prep the steel edges the following procedure was followed.

1. Samples were cut from 2 bars, 11 inch each
2. Every surface was milled to take off the corrosion
3. Drill a countersunk hole (1/4 inch) in the middle of the part to hold ski to future edge holder
4. Polish every surface, First 5 min with a 1 microns grit polishing paper then 3 minutes with a 0.05 microns grit polishing paper
5. Collect measurements of the surfaces and edges prior
6. Use the mass finisher to systematically round the edges; each edge will be a different roundness due to a different amount of time in the mass finisher

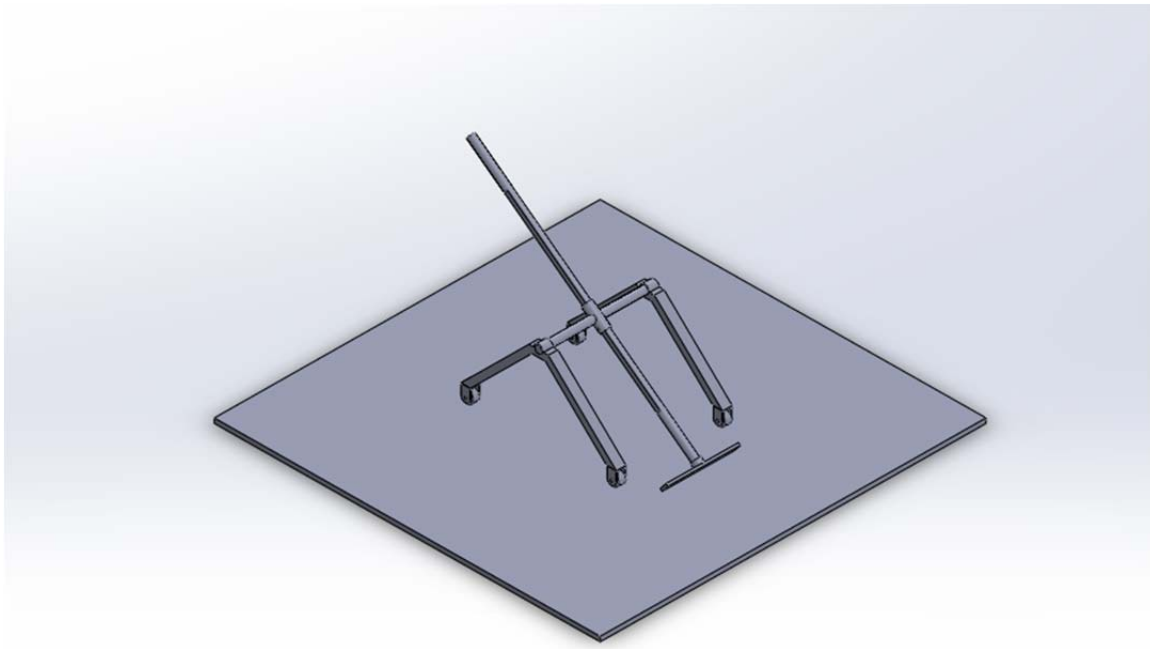
## Appendix B: Design Iterations



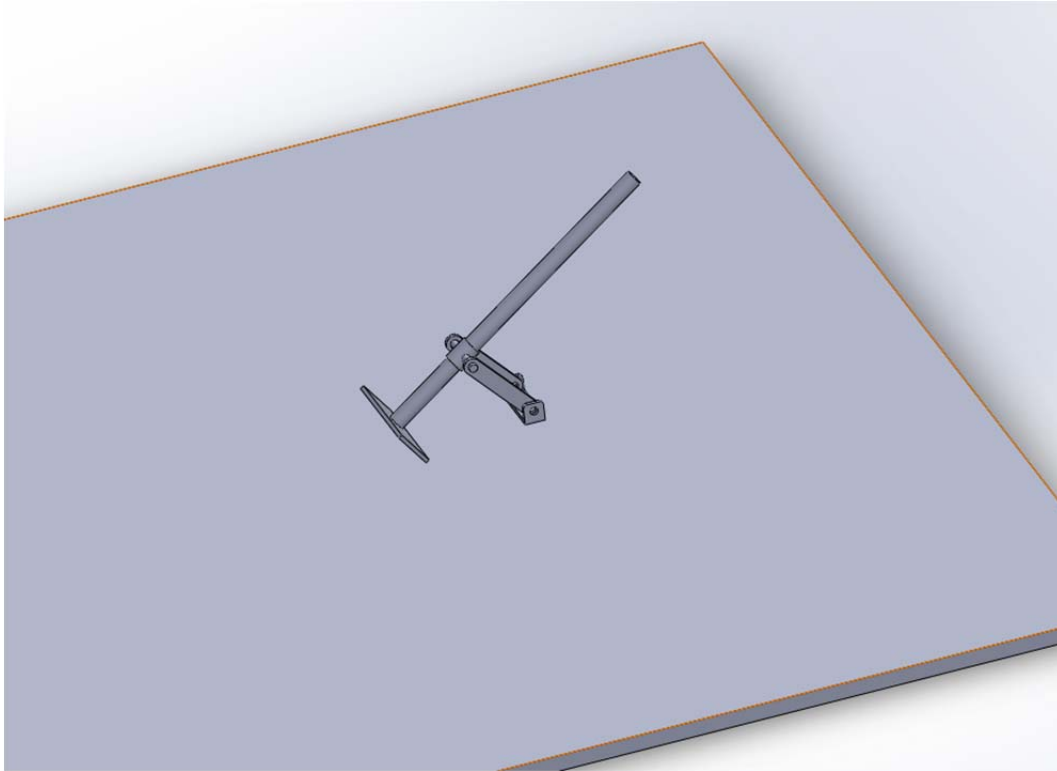
- Design 1 (tester)
  - Based on Gleason and Brown idea
  - Pole for holding and creating the arch
  - Flat at bottom for ski to be screwed into
    - Too many loose variables
    - Force created by tester inconsistent
    - Radial arch unable to be achieved
    - Perpendicular forces added (left to right)
      - Need to constrain more variables
      - Constrain force
      - Repeatability
      - Angle measurement
      - Reduce moment



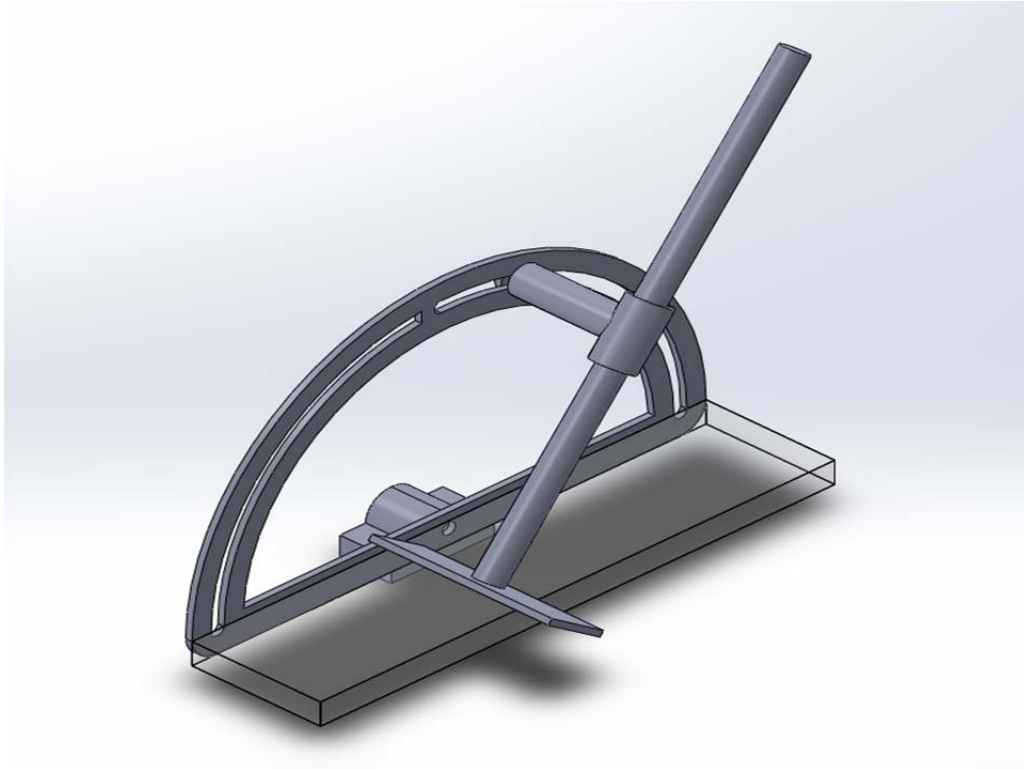
- Design 2 (tester)
  - Center parallel bar creates pivot point
  - Normal force constrained in one direction by center box
    - Weight causes moment about end of pole
    - Force has horizontal and vertical components
    - **Never used**
    - Redesign needed



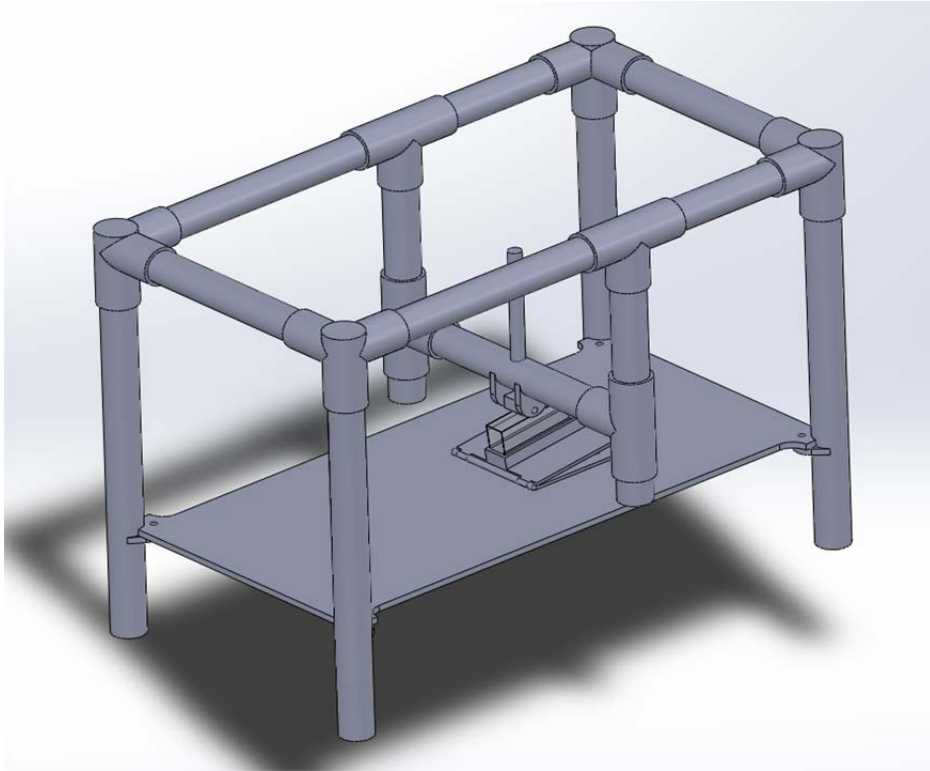
- Design 3 (tester)
  - Pivot point about top horizontal axis
  - Rollers on the stand allows movement of tangential force
  - Pass fail denoted if the whole rig is able to move (ski edge shear the ice)
    - Cant constrain magnitude of the force moving the edge
    - Force applied away from edge plane so moments created
    - Determined not viable



- Design 4 (tester)
  - Constrains perpendicular motion of the arm left to right
  - Support locked at angle
    - Arm can still slip out based on attachment bar
    - Normal force applied away from edge plane
    - Reproducibility questioned
    - Determined not viable (too simple in design)

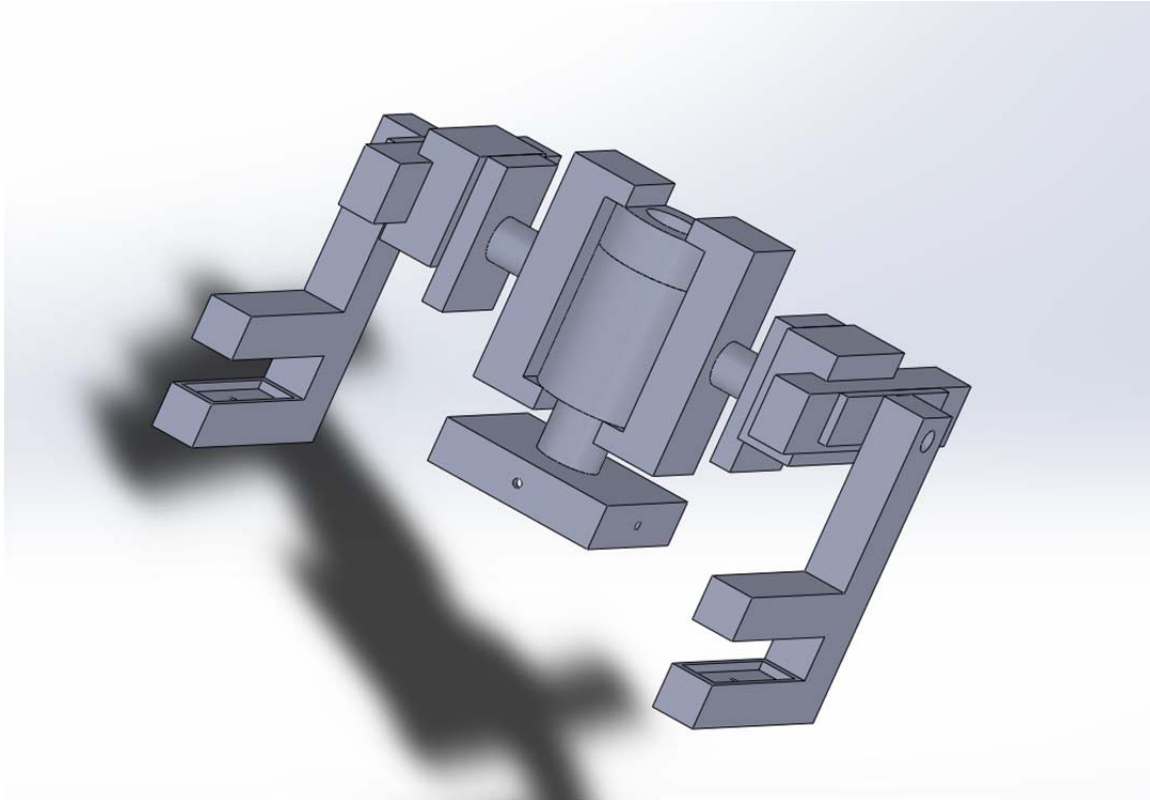


- Design 5 (tester)
  - Wheel based design creates allows edge to be pivot point
  - Arch meant to allow rotation about the edge
    - Holding wheels off the ground and allowing testing on ice become an issue
    - Edge not actually the pivot point
    - Weight not applied normally
    - Design was scrapped



- Design 6 (tester)
  - Normal force is only load that is changed
  - Upper T's allow horizontal movement
  - Lower T's allow vertical movement
  - Hinge allows adjustment in angle of edge impaction
    - Friction
    - Load based on plates creates moment issue/weight distribution
    - Large size an issue
    - Need a design that can be a tester and a final product
    - Overall a good design but not applicable to final product
    - Realize deviation and need to create combo tester/product





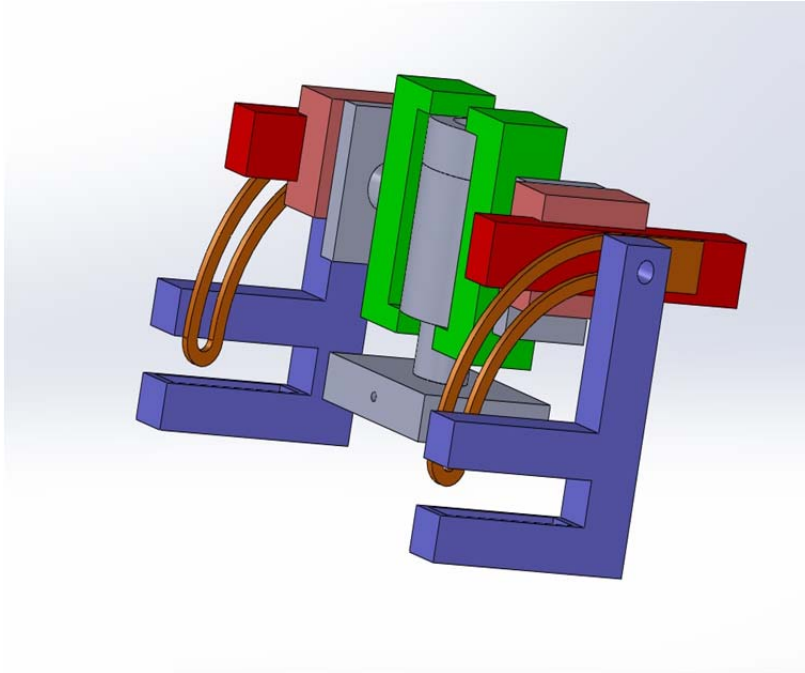
#### Design 7

What was changed from Design 6? How were these changes improving the device?

- Outside cage was removed and device was minimized because it did not coincide with our intent of design which would clamp to a ski
- Allowing for horizontal and vertical movement was changed from PVC tubing to linear bearings to decrease friction
- Normal force application was changed from free weights to a spring placed inside a vertical bearing
- Instead of moving the angle of the ice with a fixed edge on top of the ice, the angle of the ice would be rotated about the edge so as to always apply a normal force in the downward direction.

New design issues that need to be changed in the next iteration?

- Device rotates about the center axle on the Clamp connector and not the Ice as it should be to provide a normal force on the edge at all times during testing
- Clamps holding vertical bearing in place won't hold the vertical bearing and threaded cap when a tangential force is applied
- Vertical bearings and clamps could rotate about current axle, need to stop possible rotation



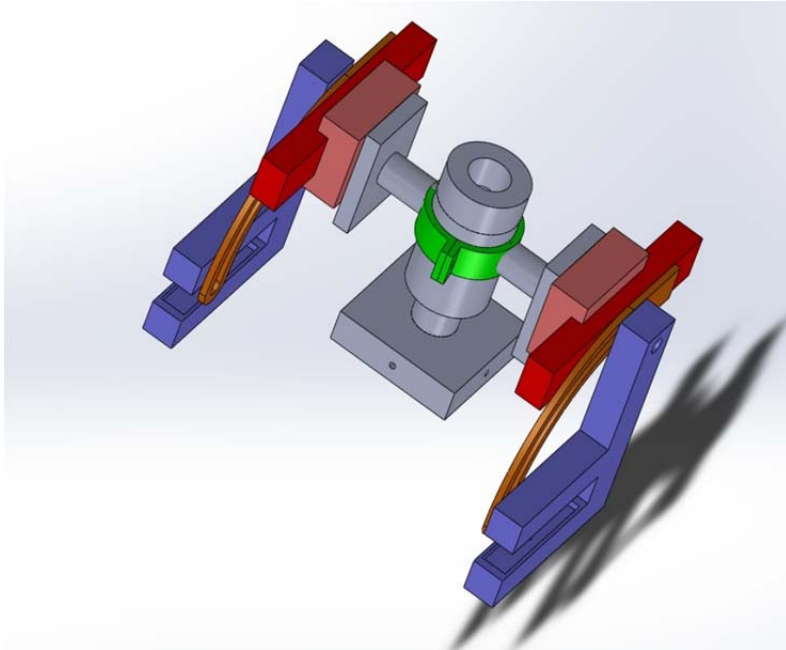
## Design 8

What was changed from Design 7? How were these changes improving the device?

- Orange arch pieces were put in place on either side of the device so as to allow rotation about the edge of the ski and not the center axle at the top of the clamp

New design issues that need to be changed in the next iteration?

- Arch pieces are too big
- Clamp pieces create rotation too far away from edge. Possible moments and unexpected forces could arise
- Clamps holding vertical bearing in place won't hold the vertical bearing and threaded cap when a tangential force is applied
- Vertical bearings and clamps could rotate about current axle, need to stop possible rotation



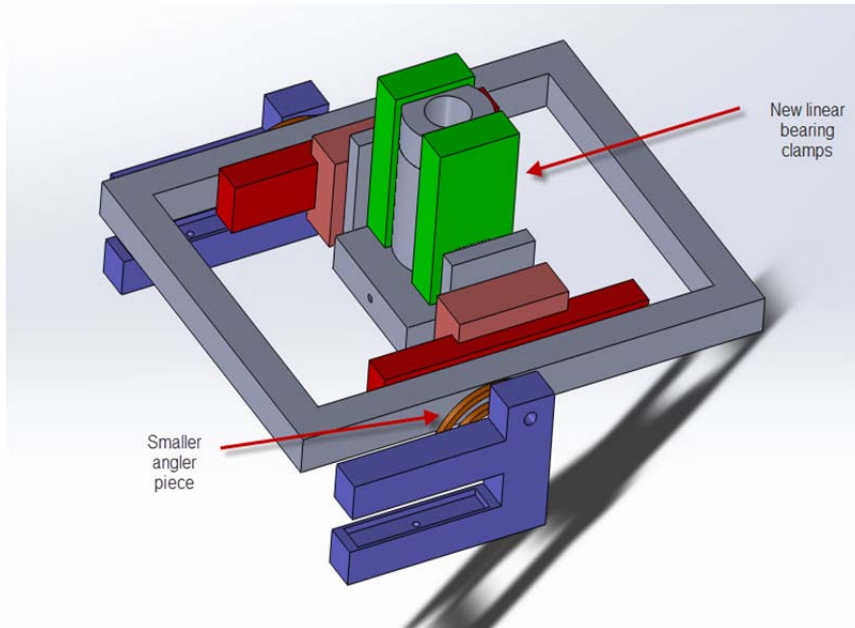
#### Design 9

What was changed from Design 8? How were these changes improving the device?

- Clamps were changed from vertical holding to C-clamps to prevent tangential motion

New design issues that need to be changed in the next iteration?

- In this configuration, the vertical bearing cap is not held in place by anything
- Box not held in place by anything. Could fall out or rotate
- Arch pieces are too big
- Clamp pieces create rotation too far away from edge. Possible moments and unexpected forces could arise



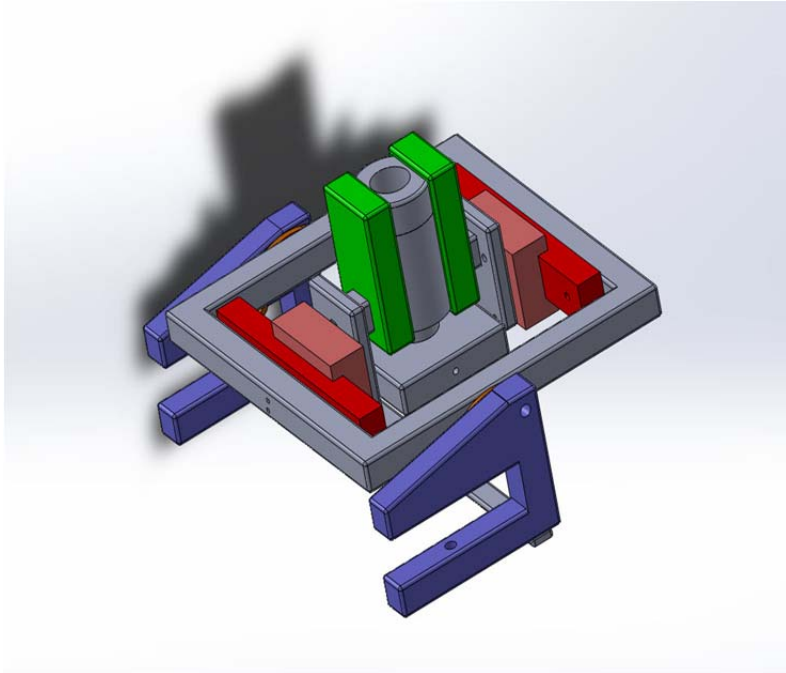
## Design 10

What was changed from Design 9? How were these changes improving the device?

- Arch pieces were made smaller and clamps connectors were also made smaller to make rotation about the edge a smaller distance.
- Rectangular frame was added to attach Horizontal linear bearings more securely and provide support for tightening at proper angle
- Vertical linear bearing clamp was re-designed to stop both normal and tangential slip
- Circular axle pieces were made square to stop rotation

New design issues that need to be changed in the next iteration?

- Not designed for ease of manufacturability ( sharp edges)
- Hole callouts not designated
- Rectangular frame should be square
  - o Design should have the ability to test both transversely and linearly to ski edge
- Possible stress concentration on top of clamp
- When clamps are loose they will fall off device
- Void in bottom of ski clamp cannot be machined. Re-design needed



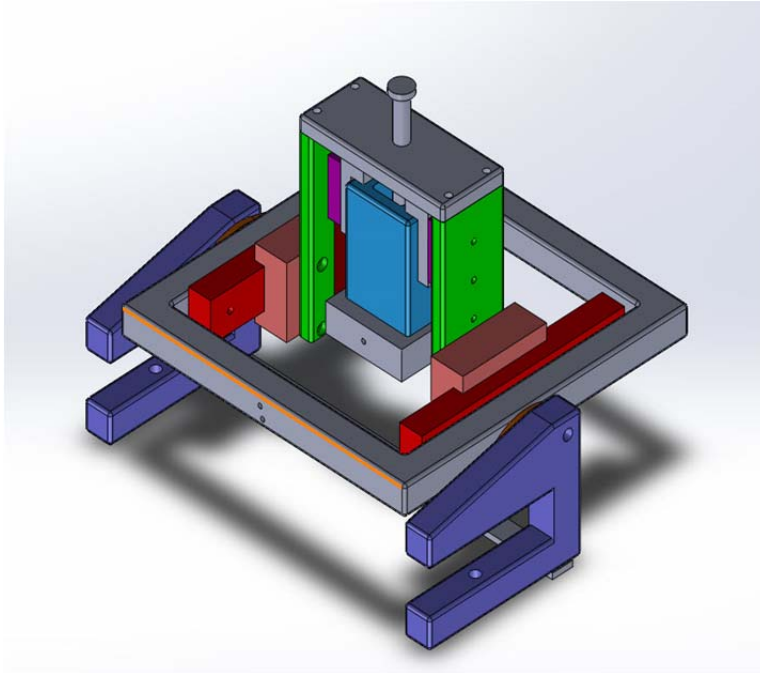
#### Design 11

What was changed from Design 10? How were these changes improving the device?

- All edges chamfered to make the device easier to manufacture and easier to hold/manipulate the device
- Hole callouts were added to all parts using standard hole sizes and thread counts
- Appropriate countersinks added where needed
  
- Rectangular tangential frame made square to accomplish two things: 1) allow for transverse and linear testing and 2) make device smaller
- Holes added to opposite sides of tangential frame so the device could test both transversely and linearly
- Material added on clamp to reduce stress concentrations
- Clamp connector piece was added to hold clamps in place when not testing/ changing conditions.
- Void in ski clamp removed and area for ski to fit was increased so all ski's could fit in device

New design issues that need to be changed in the next iteration?

- Box that holds the ice can rotate on the ice. Need to stop rotation
- Screw that provides the normal forces is too large for this device and would be difficult to manipulate



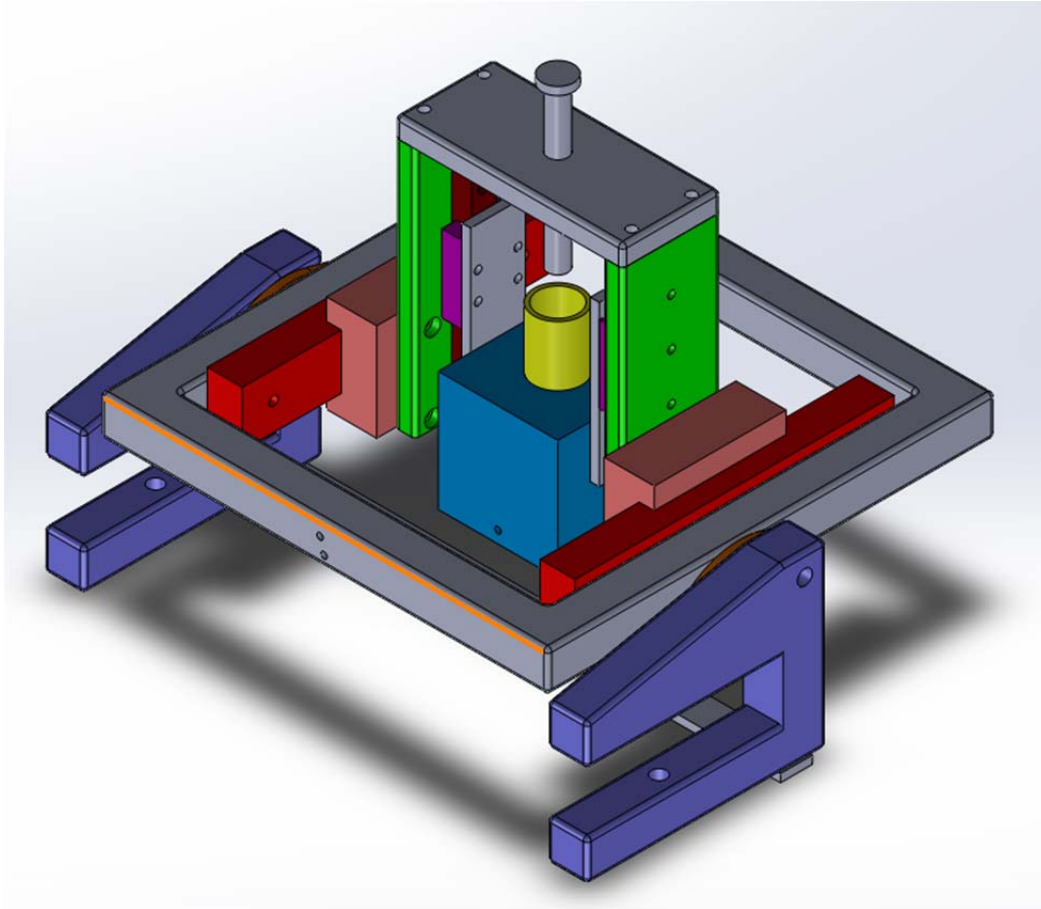
### Design 12

What was changed from Design 11? How were these changes improving the device?

- Flat pieces attached to horizontal linear bearings were extended and a top piece was added to hold a screw that would compress the spring applying the normal force. This was done to make it easier for the user to apply normal force.
- Removed circular vertical linear bearing and replaced with two straight linear bearing to reduce friction and stop rotation of the ice box
- Box attached to ice box to remove any rotation when testing. Connected to linear bearings with "L" shaped pieces to make sure normal force is still being applied properly.

New design issues that need to be changed in the next iteration?

- Box holding the spring and connected to the ice box is not able to be manufactured. Needs revision to make it easier to machine



### Design 13

What was changed from Design 12? How were these changes improving the device?

- Ice box was redesigned to allow it be connected to the linear bearings more securely
- "L" piece holding box was removed and in its place was put another flat piece of material attached directly to the ice box, so rotation is still removed
- Circular piece was made to hold the spring and was placed on top out of ice box so the spring compressor would be in line with it to apply the normal force. Connected with two screws on bottom of circular piece

New design issues that need to be changed in the next iteration?

- need to apply tangential force